

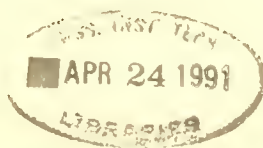
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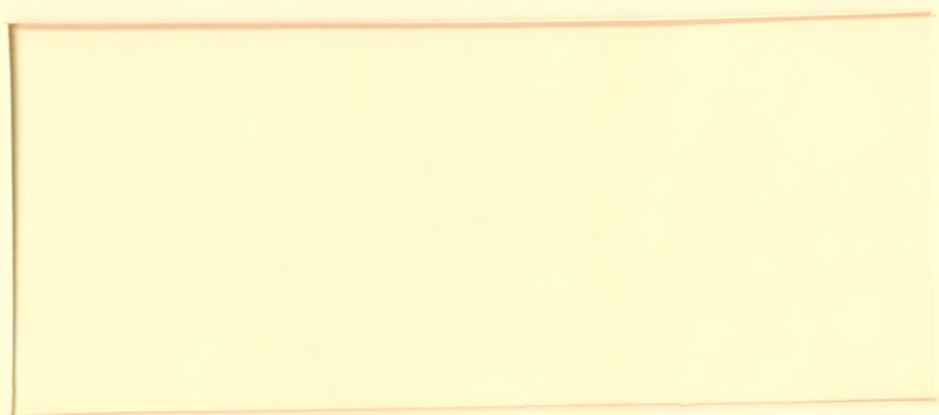
Minimum Quality Standards, Fixed Costs,
and Competition

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Abstract

I investigate the consequences of imposing a minimum quality standard on an industry in which firms face quality-dependent fixed costs and compete in quality and price. Even though the high-quality sellers would satisfy the standard in the absence of regulation, imposing a standard leads these sellers to raise qualities. They do so in an effort to alleviate the price competition, which intensifies as a result of the low-quality sellers' having raised their qualities to meet the imposed standard. However, by its very nature, a minimum quality standard limits the range in which producers can differentiate qualities. Hence, in the end, price competition intensifies and , prices – “corrected for quality change” – fall. Due to the better qualities and lower hedonic prices, and compared to the unregulated equilibrium, all consumers are better off, more consumers participate in the market, and all participating consumers – including those who would consume qualities in excess of the standard in the absence of regulation – select higher qualities. When the consumption of high-quality products generates positive externalities – as in the case of safety products – these results favor minimum quality standards. I also show that even in the absence of externalities an appropriately chosen standard improves social welfare.

1 Introduction

Minimum quality standards are often adopted to increase the qualities produced and consumed. A recent example of interest is a regulation that requires car makers to meet fuel-economy standards. It is likely that, holding other car attributes constant, consumers prefer cars with high miles-per-gallon performance, because of the savings in operational costs. The government would also prefer that consumers drive more fuel-efficient cars, but for different reasons: reducing carbon dioxide emissions, and reducing dependency on foreign oil. Consumers' demand for better gas milage which reflects only the savings in operational costs is not expected to provide car manufacturers with strong enough incentives to develop fuel-efficient cars, and therefore, a direct regulation on miles-per-gallon performance is called for.¹ A similar motivation for product regulation is found in the case of safety products, such as, cyclists' helmets and fire alarms: while individual consumers are willing to pay for better qualities, the government – for paternalistic or externality reasons – might find the free-market qualities to be insufficient. It seems therefore that oftentimes the objective of minimum quality standards (MQS) is to increase the qualities that are actually consumed, and that the adoption of an MQS policy is not necessarily related to consumers' ability to observe quality prior to purchase (as argued in Leland (1979) and Shapiro (1983)).²

A priori, it is not clear whether the simple regulatory tool of minimum quality standard is effective in raising the qualities consumed. For example, Shapiro (1983) and Besanko et al. (1988) have demonstrated that those consumers who purchase qualities in excess of the standard in the absence of regulation will not change their quality selection in response to the standard. More importantly (especially in the case of safety products) some consumers might no longer purchase the product as a result of the MQS policy, because the imposition of the standard may lead to an increase in prices and a reduction in variety. Prices

¹For a description of existing regulation and a recently proposed regulation see The Wall Street Journal, April 4, 1990, page A15, column 4.

²For example, the miles-per-gallon performance of new models is estimated by the EPA and disclosed on the sale sticker.

are expected to go up, either because of the increased costs of producing higher qualities, or because the market becomes less competitive as firms – which cannot meet the standard or do not expect their revenues to cover the increased costs of providing better qualities – decide to leave the market.³ In contrast to the above concerns, the present paper shows that when production involves fixed costs and firms compete in price, an appropriately chosen standard will actually increase consumers' participation and will cause *all* participating consumers to select higher qualities.

When choosing between alternative policies, legislators are concerned with the effects of the different policies on their constituencies' welfare. Previous research on minimum quality standards (Leland (1979) and Shapiro (1983)), has demonstrated the existence of a group of consumers who are worse off as a result of the MQS policy. They are worse off either because their favorite qualities are no longer supplied or because of the resulting higher prices. The existence of consumers who suffer as a result of the standard might discourage legislators from adopting a socially improving MQS. Contrary to these previous results and concerns, I show – again, due to the assumption of price competition in the presence of fixed costs – that *all* participating consumers are strictly better off as a result of the MQS policy.

Our results are explained by the relation between the price competition and the qualities produced: price competition intensifies as the disparity between the qualities shrinks. In response to the adoption of the MQS policy, low-quality suppliers raise their qualities to meet the standard, and thus, become closer substitutes to the high-quality suppliers. If the high-quality sellers do not raise their qualities, price competition will intensify so their revenues will fall. To alleviate this effect, the high-quality sellers also raise qualities in an effort to differentiate themselves from the low-qualities sellers. However, by its very nature, a minimum quality standard limits the range in which producers can differentiate qualities. Hence, in the end, price competition intensifies despite the high-quality sellers' efforts to relax it. Consequently, if variable costs do

³ Even in Leland's (1979) "Market for 'Lemons'" framework, where the exit of low-quality firms lead to the entry of high-quality firms, the market supply of the product may fall.

not rise “too quickly” with quality, prices – “corrected for quality change” – fall. The combination of better qualities and lower hedonic prices accounts for the increase in market participation, the selection of higher qualities by all participating consumers, and the increase in the welfare of all participating consumers.

The differences between the results reported here and those of previous research are due mostly to the assumptions about the competitive environment. While firms in our model compete in price in an oligopolistic market structure (due to the assumption of fixed costs), firms in the models of Leland (1979) and Shapiro (1983) are price takers. In Leland’s “market for lemons” potential entrants’ qualities are exogenously given; and a firm’s sole decision is whether to enter the market given the market price (on which it has no effect) and its (exogenously-given) opportunity cost. In Shapiro (1983), there are infinitely many potential entrants at each quality level and no fixed costs, implying that an individual seller has no effect on prices. Hence, these two models – as well as Besanko, Donnenfeld, and White’s (1988) model of a multi-product monopolist – cannot capture the effect of a minimum quality standard on the intensity of price competition.

We argued before that minimum quality standards are often imposed on goods with consumption externalities and their objective is to raise the qualities consumed. In this paper I also show that even in the absence of externalities an appropriately chosen standard improves social welfare. I identify two sources of welfare loss. One source is the usual difference between marginal consumer valuation for quality and average consumer valuation (see, for example, Spence (1976)), which gives rise to an “underprovision” of quality in both market segments. The other source is the competitors’ incentive to alleviate price competition, which gives rise to an “excess” of quality differentiation that results in a thin market participation and a non-optimal market segmentation. By raising *both* qualities and reducing quality differentiation, the MQS policy alleviates all of these distortions.

Finally, I show that as a result of the standard, *low*-quality sellers can be better off (even though the standard constrains their action space it gives them

a strategic advantage), and that *high*-quality sellers are worse off (even though they would meet the standard in the absence of regulation they suffer from the more intense price competition). This somewhat surprising result differs from previous results in the MQS literature. In Leland's model low-quality sellers are worse off (they cannot meet the standard and therefore are forced to leave the market) and high-quality sellers are better off (market price goes up). In Shapiro's model all sellers are indifferent (there are no abnormal returns).

In the next section I set up the model. In Section 3 I derive the results, and in Section 4 I discuss some generalizations. Section 5 concludes the paper.

2 The Model

The basic features of the model used are standard in studies of quality differentiation with monopolistic competition (e.g., Gabszewicz and Thisse (1979), Shaked and Sutton (1982), and Champsaur and Rochet (1989)). The demand side of the market consists of a continuum of consumers indexed by s and uniformly distributed on $[0, 1]$. Let $v(s, q) = s \cdot q$ be the value that consumer s places on quality q . The surplus of consumer s who purchases quality q and pays p is therefore given by $sq - p$. We assume that an individual consumer derives utility only from the first unit he buys.

There are two potential entrants to the market. They are identical in all respects. In particular, each of them is constrained to offer only one quality, and each of them faces the same costs of developing the technology that enables the provision of quality q . These quality development costs, $C(q)$, and their respective marginal costs, $C'(q)$ are assumed to be increasing functions of q , that is, $C'(\cdot) > 0$ and $C''(\cdot) > 0$ for all feasible qualities $q \in [0, \infty)$. Throughout the analysis we shall also maintain the regularity assumptions that $C(0) = C'(0) = 0$ and that $\lim_{q \rightarrow \infty} C'(q) = \infty$. In Sections 2 and 3 we assume that there are no unit production costs. This assumption is relaxed in Section 4, where we also show that our analysis generalizes to markets with infinitely many potential entrants.

The competition between the firms takes place in two stages. At each stage

the firms make their decisions simultaneously. The first stage decisions become observable before the the second stage starts. In the first stage, each firm decides whether or not to enter the market and how much to invest in quality development. A firm can enter the market only if its quality exceeds the minimum quality standard, denoted by q_{min} . If both firms enter the market, price competition takes place in the second stage. If only one firm enters, it becomes a monopolist and sets its price accordingly. The two stage modeling captures the notion that a firm can change its prices almost instantaneously, whereas a change in the technology takes a nontrivial amount of time. Consumers are price and quality takers: given the firms' decisions, $(q_i, p_i)_{i=1,2}$, each consumer has to choose between purchasing one unit from firm 1, purchasing one unit from firm 2, or making no purchase.

The solution concept we employ is Subgame Perfect Equilibrium. The equilibrium is solved in two steps. First, we find the second-stage price equilibrium. If only one firm enters the market in the first stage, it becomes a monopolist in the second stage. One can easily verify that the optimal price of a monopolist who entered the market with quality q_i is $\frac{1}{2}q_i$, and its market share is $[\frac{1}{2}, 1]$. If both of the firms enter the market, then the second-stage subgame is defined by a pair $(q_H, q_L) \in [q_{min}, \infty) \times [q_{min}, \infty)$, such that $q_H \geq q_L$. The subscript H denotes the firm which has entered the market with a quality that exceeds the quality of the other firm. This firm is labeled the *high-quality seller*. The other firm is labeled the *low-quality seller* and it is denoted by the subscript L . In the Appendix we show that when the two firms are in the market, the second-stage subgame has a unique price equilibrium. In this equilibrium, the quality-deflated price of the low-quality seller ($x_L \equiv \frac{p_L}{q_L}$), the quality-deflated price of the high-quality seller ($x_H \equiv \frac{p_H}{q_H}$), and the marginal consumer who is indifferent between q_H at price p_H and q_L at price p_L ($z \equiv \frac{p_H - p_L}{q_H - q_L}$) are equal to

$$x_L = \frac{r-1}{4r-1}, \quad x_H = \frac{2(r-1)}{4r-1} \quad \text{and} \quad z = \frac{2r-1}{4r-1}, \quad (1)$$

respectively, where $r \equiv \frac{2H}{q_L}$. Notice that x_L is also the marginal consumer who is indifferent between purchasing q_L and making no purchase. The equilibrium market shares of the low-quality seller and the high-quality seller are therefore

shown to be $[x_L, z]$ and $[z, 1]$, respectively. The equilibrium revenue functions are obtained by multiplying each firm's equilibrium price by its equilibrium market share:

$$\begin{aligned} R_L(q_H, q_L) &= q_L x_L(z - x_L) = q_L \frac{r(r-1)}{(4r-1)^2} \quad \text{for } q_H \geq q_L > 0 \\ R_H(q_H, q_L) &= q_H x_H(1 - z) = q_H \frac{4r(r-1)}{(4r-1)^2} \quad \text{for } q_H \geq q_L > 0. \end{aligned} \quad (2)$$

Since the second-stage revenues of both firms are uniquely determined by q_H and q_L , we can take advantage of the Subgame Perfect Equilibrium notion and define the competitors' payoffs in terms of their first stage decisions. The profits of firm i as a function of its first stage decision, q_i , and its competitor's first stage decision, q_j , are thus given by

$$\begin{cases} R_H(q_i, q_j) - C(q_i) & \text{if } q_i \geq q_j \geq q_{min} \\ R_L(q_j, q_i) - C(q_i) & \text{if } q_{min} \leq q_i \leq q_j \\ \frac{1}{4}q_i - C(q_i) & \text{if } j \text{ doesn't enter} \\ 0 & \text{if } i \text{ doesn't enter.} \end{cases}$$

There are three cases to consider. If q_{min} is very high, so that $\frac{1}{4}(q_{min}) < C(q_{min})$, then it would be impossible – even for a monopolist – to cover the cost of developing a quality that meets the mandated standard. In this case neither firm enters the market. For other values of q_{min} , either there is a unique equilibrium with one firm entering (when q_{min} is high), or there is a unique equilibrium with both firms entering (when q_{min} is low), or there are two possible equilibria with one or both firms entering (for intermediate values of q_{min}). In the next subsection we prove that the unique equilibrium in the unregulated market, i.e., the market in which $q_{min} = 0$, has both firms active in the market. In Section 3, we show that if the minimum quality standard is not set too high (in a sense that is made precise later), the equilibrium in which both firms enter the market continues to exist. By comparing the equilibria before and after the mandating of q_{min} , we are able to identify the consequences of the MQS policy as outlined in the Introduction.

The following are easily verified properties of R_H and R_L , which we shall use extensively in the rest of the paper. They account for and provide the intuition

for the effects of the MQS policy. The properties are stated in terms of the marginal revenue functions, $MR_H \equiv \frac{\partial R_H}{\partial q_H}$ and $MR_L \equiv \frac{\partial R_L}{\partial q_L}$, and the marginal cost function, $MC \equiv C'$. They are derived using the convention that $q_H \geq q_L$.

$$\forall q_L > 0 : \frac{\partial MR_H}{\partial q_H} < 0, \quad \lim_{q_H \rightarrow \infty} MR_H = MC(q_M) = MR(q_M) \quad (a) \quad (3)$$

$$\forall q_H > 0 : \frac{\partial MR_L}{\partial q_L} < 0, \quad MR_L(q_H, 0) > 0 > MR_L(q_H, q_H) \quad (b) \quad (3)$$

$$\forall q_H > q_L : \frac{\partial R_H}{\partial q_L} < 0 \quad ; \quad \forall q_L > 0 : \frac{\partial R_L}{\partial q_H} > 0 \quad (c) \quad (3)$$

$$\forall q_H > q_L : \frac{\partial MR_H}{\partial q_L} > 0 \quad ; \quad \forall q_L > 0 : \frac{\partial MR_L}{\partial q_H} > 0 \quad (d) \quad (3)$$

where $q_M \equiv MC^{-1}(\frac{1}{4})$ is the monopolist's choice when $q_{min} \leq MC^{-1}(\frac{1}{4})$.

To understand the economic content of these properties, recall that price competition intensifies as the disparity between the qualities shrinks and the qualities become closer substitutes to each other. This relation between quality differentiation and price competition is manifested in equation (1), where the quality-adjusted prices, x_H and x_L , fall as the differentiation between the qualities, as measured by r , contracts. Equation (3-c) exhibits that the high-quality seller's revenues decrease as the low-quality seller raises his quality and thus becomes a closer substitute to the high-quality seller ($\frac{\partial R_H}{\partial q_L} < 0$). It also exhibits that the low-quality seller's revenues rise as the high-quality seller raises his quality and thus expands the disparity between the qualities ($\frac{\partial R_L}{\partial q_H} > 0$).

Equations (3-a,b) demonstrate that R_H is concave in q_H and that R_L is concave in q_L . One can easily conclude from these two properties and from the assumption that C is convex that each firm will strive to equate its marginal revenues to its marginal costs. Since MC is exogenously given, it follows that the sole strategic interaction between the firms in the first stage of the game is through the effects of one's choice of quality, say q_i , on its rival's marginal revenue curve, MR_j . We elaborate on these interactions below.

Equation (3-b) demonstrates that at low-quality levels, the low-quality seller can increase his revenues by raising his quality, but as his quality approaches the

quality of the high-quality seller, price competition intensifies and his revenues decline as a result. This price-competition effect deters the low-quality seller from raising his quality too much. Particularly, as the high-quality seller raises quality and thus expands the disparity between qualities, the price-competition effect is alleviated, and as a result, the low-quality seller has a stronger incentive to raise quality ($\frac{\partial MR_L}{\partial q_H} > 0$ in equation (3-d)). Similarly, when the low-quality seller raises quality and thus becomes a closer substitute to the high-quality seller, the incentive of the high-quality seller to differentiate himself from the low-quality seller becomes stronger ($\frac{\partial MR_H}{\partial q_L} > 0$).

2.1 The Equilibrium in the Unregulated Market

Consider first the low-quality seller's best response to q_H . For a given choice of the high-quality seller, q_H , the low-quality seller maximizes $R_L(q_H, \cdot) - C(\cdot)$ subject to $q_L \leq q_H$. This problem has a unique solution, since MR_L is continuous and decreasing in q_L from some positive value at $q_L = 0$ to some negative value at $q_L = q_H$ (see equation (3-b)), while MC is continuous and strictly increasing from 0 at $q_L = 0$ to some positive value at $q_L = q_H$. Thus, if q_L is an equilibrium choice of one of the firms, it must satisfy

$$MR_L(q_H, q_L) = MC(q_L) \quad . \quad q_L \in (0, q_H) \quad . \quad (4)$$

Using equation (4), we can define a function $b_L(\cdot)$ whose domain is $(0, \infty)$, that ascribes the best response of firm i against q_j on $[0, q_j]$. By fully differentiating (4) with respect to q_H , we obtain that

$$\frac{1}{r} > \frac{\partial b_L(q_H)}{\partial q_H} = \frac{\partial MR_L}{\partial q_H} / (C'' - \frac{\partial MR_L}{\partial q_L}) > 0 \quad , \quad (5)$$

where the first inequality follows from Euler's theorem,⁴ and the second inequality follows from equation (3-b,d). The function b_L is only a *restricted* best response, because for a relatively low q_j , the *true* best response of player i is to enter the market as the high-quality seller with some $q_i \in (q_j, \infty)$. Notice also that since $MR_L(q_H, 0) > MC(0)$ for all $q_H > 0$ (by equation (3-b)), a firm

⁴The revenue functions are linearly homogeneous (see equation (2)). Therefore, the marginal revenue functions are homogeneous of degree zero, implying that $q_L(\partial MR_L)/\partial q_L + q_H(\partial MR_L)/\partial q_H = 0$.

can always earn positive profits by entering the market as the low-quality seller, and therefore, it cannot be the case that only one firm enters the market in equilibrium.

Consider now the high-quality seller best response to q_L . Since MC is increasing and MR_H is decreasing in q_H , $R_H(\cdot, q_L) - C(\cdot)$ can be positive only if $q_L \in \{q \mid MR_H(q, q) > MC(q)\}$. In that case, MR_H uniquely crosses MC at some $q_H \in (q_L, \infty)$. Thus, if q_H is an equilibrium choice of one of the firms, it must satisfy

$$MR_H(q_H, q_L) = MC(q_H) \quad , \quad q_H \in (q_L, \infty) \quad . \quad (6)$$

Using equation (6), we can define a function $b_H(\cdot)$ whose domain is $\{q \mid MR_H(q, q) > MC(q)\}$, that ascribes the best response of firm i against q_j on $[q_j, \infty)$. By fully differentiating (6) with respect to q_L , we obtain that

$$r > \frac{\partial b_H(q_L)}{\partial q_L} = \frac{\partial MR_H}{\partial q_L} / (C'' - \frac{\partial MR_H}{\partial q_H}) > 0 \quad , \quad (7)$$

where the inequalities follow from equation (3-a,d) and Euler's theorem. The function b_H is only a *restricted* best response, because for a relatively high q_j , the *true* best response of player i is to enter the market as the low-quality seller with some $q_i \in (0, q_j)$. Obviously, $b_H(0) = q_M$.

Theorem 1

(a) *There exists a unique pair, (q_H^{ur}, q_L^{ur}) , that satisfies the necessary conditions (4) and (6).*

(b) *Both firms earn positive profits when (q_H^{ur}, q_L^{ur}) is played.*

(c) *$C''' \geq 0$ is a sufficient condition for the pair (q_H^{ur}, q_L^{ur}) to be an equilibrium.*

Proof:

A simple application of Euler's theorem shows that the domain of b_H is $[0, \bar{q}]$, where $\bar{q} > 0$ is the unique solution to the equation $MR_H(q, q) = MC(q)$. Obviously, $b_H(\bar{q}) = \bar{q}$. Let $B(q) \equiv b_L[b_H(q)] - q$. The function $B : [0, \bar{q}] \rightarrow [0, \bar{q}]$ is continuous and strictly decreasing, since, by equations (5) and (7), $\partial B / \partial q = b'_H b'_L - 1 < 0$. Clearly, $B(0) > 0$ and $B(\bar{q}) < 0$, and therefore, there exists a unique $q_L^{ur} \in [0, \bar{q}]$ satisfying $B(q_L^{ur}) = 0$. The proofs of parts (b) and (c) are

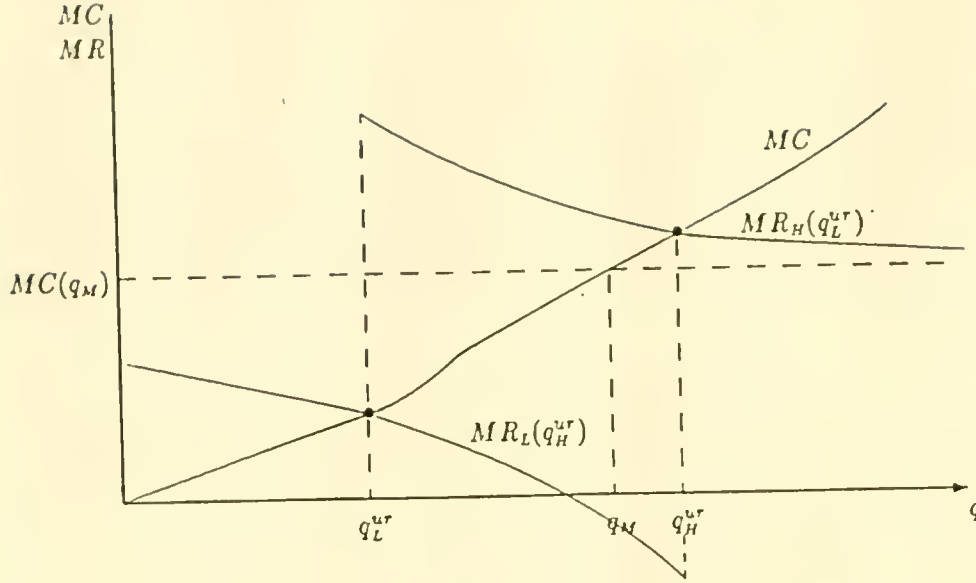


Figure 1: The unregulated market: necessary conditions for equilibrium

presented in the Appendix.⁵ ■

In the rest of the paper, the superscript *ur* will indicate the equilibrium in the *unregulated* market. The properties of MR_H and MR_L , the assumption about MC , and the necessary conditions (4) and (6) imply that the marginal cost curve, the marginal revenue curves, and the pair (q_H^{ur}, q_L^{ur}) are as in Figure 1. The functions b_H and b_L and their relation to (q_H^{ur}, q_L^{ur}) are depicted in Figure 2.

3 Consequences of a Minimum Quality Policy

In the last section, we defined the MQS policy as the requirement that a firm which is active in the market must exceed some specified quality level. Having found the equilibrium qualities in the unregulated market, we are now in a position to investigate the economic consequences of setting the minimum quality standard, q_{min} , above the unregulated low quality level, q_L^{ur} .

⁵The proof of part (b) is tedious because the first order conditions do not imply directly that the high-quality seller enjoys positive profits. The intuition that $C''' > 0$ is a sufficient condition for existence is that a steep MC curve guarantees that $b_L(q_H^{ur})$ is a true best response.

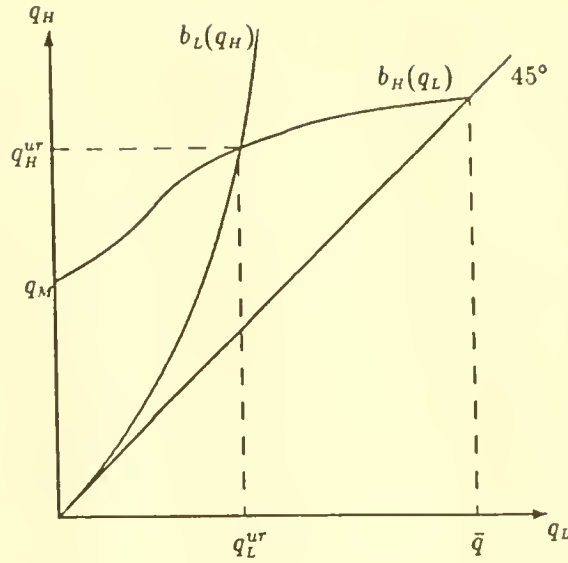


Figure 2: Restricted best responses: b_H and b_L

A firm entering the market when the MQS policy is in place needs to invest at least $C(q_{min})$ in quality development. Given the ensuing price competition – and, as we shall see, the MQS policy intensifies price competition – revenues may not be sufficient to cover the initial investment. It is possible therefore that the minimum quality standard is a barrier to entry. While our model acknowledges that an MQS policy may reduce the number of entrants, it also demonstrates – see the next theorem – that if the minimum quality standard is not set “too high” above q_L^{ur} , the equilibrium in which both firms enter the market continues to exist. In this section, we identify the effects of the MQS policy by comparing the equilibrium in which both firms enter the market – this equilibrium will be denoted by the superscript *mq*s – with the equilibrium of the unregulated market, which continues to be denoted by the superscript *ur*. There may also be an additional equilibrium with only one firm in the market. This possibility is discussed at the end of the section, where we argue that this monopolistic equilibrium is not reasonable.

Theorem 2 *There exists an interval (q_L^{ur}, q_*) , such that if the minimum quality standard, q_{min} , is set within (q_L^{ur}, q_*) , the market has an equilibrium in which both firms enter the market. Compared to the unregulated market equilibrium, and as a result of the MQS policy,*

(a) *both firms raise their qualities: $q_H^{mq} > q_H^{ur}$ and $q_L^{mq} = q_{min} > q_L^{ur}$,*

- (b) *more consumers are active in the market, and*
(c) *consumers who were active in the unregulated market purchase a product of a higher quality.*

Proof: It is clear from Figure 2 that if both firms are in the market and $q_{\min} > q_L^{ur}$, then $q_L^{mqs} = q_{\min} > q_L^{ur}$ and $q_H^{mqs} = b_H(q_{\min}) > q_H^{ur}$. Since both firms enjoy positive profits in the unregulated market, and since $R_H(b_H(q_L), q_L) - C(b_H(q_L))$ and $R_L(b_H(q_L), q_L) - C(q_L)$ are continuous in q_L , there exists some $q_* > q_L^{ur}$, such that if $q_{\min} \in (q_L^{ur}, q_*]$, the profits of both sellers are positive when $(b_H(q_{\min}), q_{\min})$ is played. Hence, $(b_H(q_{\min}), q_{\min})$ is an equilibrium when $q_{\min} \in (q_L^{ur}, q_*]$. To prove parts (b) and (c), notice that since $q_L^{mqs} = q_{\min}$ and $q_H^{mqs} = b_H(q_{\min})$,

$$\frac{dr}{dq_{\min}} = \frac{b'_H - r}{q_L} < 0,$$

where the inequality follows from equation (7). We conclude therefore that $r^{mqs} < r^{ur}$. Recall that the low-quality seller's market share is $[x_L, z]$, that the high-quality seller's market share is $[z, 1]$. Since $\frac{\partial x_L}{\partial r} > 0$, the decline of r implies that market participation increases from $[x_L^{ur}, 1]$ to $[x_L^{mqs}, 1]$. This proves part (b). Since $\frac{\partial z}{\partial r} > 0$, the decline of r implies that only consumers in $[z^{mqs}, z^{ur}]$ switched suppliers and all of them switched from the low-quality seller to the high-quality seller. This observation, in conjunction with part (a), proves part (c) (see Table 1). ■

The minimum quality policy takes advantage of the fact that price competition intensifies as the disparity between the qualities shrinks. First, to alleviate the effects of the more intense price competition on his revenues, the high-quality seller raises his quality in reply to the low-quality seller's having raised his quality to the mandated minimum quality level. Second, since improving the quality is more costly to the high-quality seller than to the low-quality seller ($C'' > 0$), the proportional increase in q_H is less than the proportional increase in q_L , that is, $r^{mqs} < r^{ur}$ (see Figure 3). As a result, the price competition intensifies despite the high-quality seller's efforts to relax it. Due to the more intense price competition, both products become more affordable, in the sense that their he-

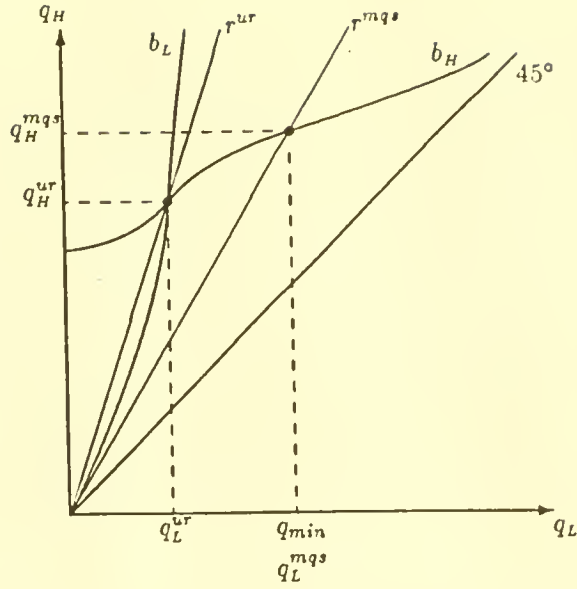


Figure 3: Consequences of MQS (Theorem 2)

donic prices, x_H and x_L , have fallen. Facing better and more affordable qualities, some of the consumers who were not active in the unregulated market decide to purchase the product, while some other consumers decide to switch from the low-quality supplier to the high-quality supplier. The changes in market shares and the change in consumers' decisions are summarized in Table 1.

<i>consumers' interval</i>	<i>in the unregulated market</i>	<i>when MQS is in place</i>
$[0, x_L^{mq}]$	no	no purchase
$[x_L^{mq}, x_L^{ur}]$	purchase	purchase
$[x_L^{ur}, z^{mq}]$	purchase	q_L^{mq}
$[z^{mq}, z^{ur}]$	q_L^{ur}	purchase
$[z^{ur}, 1]$	purchase q_H^{ur}	q_H^{mq}

Table 1: The effects of MQS on consumers' decisions and market shares⁶

As argued in the Introduction, often the objective of the MQS regulation is to increase the qualities consumed. Table 1, in conjunction with Theorem 2, demonstrates that a minimum quality standard can be quiet effective in raising the qualities consumed: as a result of the standard, (1) all the consumers

⁶The partition in Table 1 follows from Theorem 2: $x_L^{ur} > x_L^{mq} > 0$ and $z^{ur} > z^{mq}$; and from equation (1): $x_L(\bar{r}) < z(\bar{r}) < 1$ for all $\bar{r} > 1$ and $\bar{r} > 1$.

who participated in the unregulated market — including those who consumed qualities in excess of the standard — consume higher qualities; and (2) some of the consumers who did not participated in the unregulated market decide to purchase the product. In contrast to these two (unambiguous) positive results, Shapiro (1983) and Besanko et al. (1988) conclude that the MQS policy does not affect the quality selection of consumers who would purchase qualities in excess of the standard in the absence of regulation, and Leland (1979) concludes that the consumed quantity (i.e., $1 - x_L$) can actually decline as a result of the standard (due to the exit of sellers whose exogenously-given qualities are below the standard).

3.1 The Effects of the MQS Policy on Welfare

The next three theorems examine the welfare effects of MQS when the standard is set within the interval (q_L^{ur}, q_*) and both firms enter the market. The possibility of having only one firm in the market is analyzed toward the end of the section.

Theorem 3 *Compared to the equilibrium of the unregulated market, and as a result of the MQS policy, all consumers are weakly better off and those who participate in the market are strictly better off.*

Proof: Theorem 2 and its proof show that $q_i^{mq_s} > q_i^{ur}$ and that $x_i^{mq_s} < x_i^{ur}$ for $i = L, H$. It follows that the surplus consumer s derives from product i when MQS is in place, $q_i^{mq_s}(s - x_i^{mq_s})$, is strictly higher than the surplus he derives in the unregulated market, $q_i^{ur}(s - x_i^{ur})$, for both $i = L, H$ and all $s \in [0, 1]$. It is obvious then that all participating consumers, i.e., consumers in $[x_L^{mq_s}, 1]$, are strictly better off as a result of the MQS policy. Non-participating consumers are indifferent. ■

The result that *all* consumers who participate in the market are *strictly* better off as a result of the MQS policy differs from related results in the MQS literature. The typical result in the literature (e.g., Leland (1979) and Shapiro (1983)) is that the consumers with the low sensitivity to quality are worse off as a result

of the MQS policy, either because their favorite qualities are excluded from the market or because the prices of the remaining qualities have gone up. The existence or non-existence of consumers who suffer as a result of the standard can be an important issue, since the existence of such a group might encourage legislators to object to the adoption of a socially desirable standard.

Theorem 4 *Compared to the equilibrium of the unregulated market, and as a result of the MQS policy, (a) the high-quality seller is always worse off, and (b) the low-quality seller is better off if q_{min} is sufficiently close to q_L^{ur} .*

Proof:

Recalling that $q_L^{mq_s} = q_{min}$ and using the envelope theorem, we observe that

$$\frac{d}{dq_L}[R_H(q_H, q_L) - C(q_H)] = \frac{\partial R_H}{\partial q_L} < 0,$$

where the inequality follows from equation (3-c). (It is easy to see that part (a) holds for any $q_{min} \in [q_L^{ur}, q_*]$.) Similarly,

$$\frac{d}{dq_L}[R_L(q_H, q_L) - C(q_L)] = \frac{\partial R_L}{\partial q_H} \cdot b'_H > 0,$$

since b_H is upward sloping and $\partial R_L / \partial q_H < 0$ by equation (3-c). ■

That the low-quality seller has increased profits as a result of a regulation that effectively constrains his own action space without effectively changing his rival's action space lies in contrast to predictions in the existing literature. In Leland (1979), where the quality of each seller is exogenously given, low-quality sellers are worse off as a result of the MQS policy since they are not able to meet the imposed standard, and therefore, are forced to leave the market. In Shapiro (1983), where there is free entry with no fixed costs, hence no abnormal returns, all firms are indifferent to the MQS policy. In our model, the low-quality seller is better off, because the MQS policy actually endows him with the ability to commit credibly to develop the quality q_{min} . In the unregulated market, if the low-quality seller attempts to achieve the same profit level he achieves under the MQS regulation by playing q_{min} , then, *given* the high-quality seller best response to it, $b_H(q_{min})$, the low-quality seller would prefer more quality differentiation,

that is, $b_L(b_H(q_{min})) < q_{min}$. Thus, without a credible commitment device, such as the minimum quality standard, $(b_H(q_{min}), q_{min})$ can not be an equilibrium. A different interpretation of the result is that the MQS policy confers on the low-quality seller the first move advantage subject to the restriction that his choice, q_L , would allow the other firm to enter the market as the high-quality seller, i.e., $R_H(b_H(q_L), q_L) - C(b_H(q_L)) \geq 0$. The proof of part (b) shows that the low-quality seller would choose a quality above q_L^{ur} if he was the first mover, and that the MQS policy enables him to choose a quality that is closer to the choice of a stackelberg leader.

Our result that the high-quality seller is worse off as a result of the MQS policy also differs from the results of Leland and Shapiro. In Leland's model, high-quality sellers benefit from the MQS policy since it excludes low-quality sellers from the market and thus raise the product price, and in Shapiro's model, as explain above, high-quality sellers break even before and after the MQS regulation. In our model, the high-quality seller is worse off, because the MQS policy makes the low-quality seller a better substitute to the high-quality seller, and, in the presence of quality-dependent costs, makes it harder to the high-quality seller to differentiate himself from the low-quality seller.

The next theorem examines the effect of MQS on the standard welfare measure of net economic benefits, the difference between the aggregate value of consumption and the cost of supply: $W = \int_0^1 s \cdot q(s) ds - \sum_{i=1}^2 C(q_i)$, where $q(s)$ is the quality of the product consumer s purchases.

Theorem 5 *If the minimum quality standard, q_{min} , is set sufficiently close to the unregulated low-quality level, q_L^{ur} , then the social welfare, W , is improved.*

Proof: Recalling that $dq_L = dq_{min}$ and $dq_H = dq_{min} b'_H$, we evaluate the full derivative of $W = q_L \int_{x_L}^z s ds + q_H \int_z^1 s ds - C(q_H) - C(q_L)$ with respect to q_{min} at the unregulated market equilibrium, and show that it is positive.

$$\begin{aligned} \frac{d}{dq_{min}} W = & - \frac{dr}{dq_{min}} \left[\frac{\partial x_L}{\partial r} q_L x_L + \frac{\partial z}{\partial r} z (q_H - q_L) \right] \\ & + \left[\int_{x_L}^z s ds - MC(q_L) \right] + b'_H \left[\int_z^1 s ds - MC(q_H) \right]. \end{aligned} \quad (8)$$

Substituting MR for MC and straightforward calculations show that the second and third expressions on the right hand side are positive, implying an under-

provision of quality in both market segments.⁷ The first expression represents the effect of more intense price competition (i.e., lower r). It is the sum of the changes in the value of the product to consumers in the second and fourth intervals of Table 1. It is positive by previous results. ■

Equation (8) identifies two sources of welfare loss in the unregulated market. One source is the usual disparity between marginal consumer valuation for quality and average consumer valuation (see, for example, Spence (1976)). This cause is reflected in the difference between marginal social benefits and marginal revenues, and gives rise to an under-provision of quality in both market segments ($\int_{x_L}^z s ds > MC(q_L) = MR_L$ and $\int_z^1 s ds > MC(q_H) = MR_H$).⁷ By raising *both* qualities, the MQS policy alleviates the problem of under-provision of quality in both market segments. The other source of welfare loss is the competitors' incentive to relax price competition. This cause gives rise to an excess of quality differentiation which the MQS policy also alleviates. The social benefits from reducing quality differentiation are reflected in the first term of equation (8): market participation increases and higher qualities are purchased by those consumers who switch suppliers.

The equilibrium identified in Theorem 2 is not necessarily unique. There might be another equilibrium in which only one firm enters the market with the monopolistic quality q_M , where $q_L^{ur} < q_M < q_H^{ur}$ as depicted in Figure 1.⁸ When q_{min} is set sufficiently close to q_L^{ur} , however, this monopolistic equilibrium is not viable in the following sense. Assume that the firms are already active in the unregulated market (at q_L^{ur} and q_H^{ur}) when the MQS policy is imposed, and therefore, the additional costs the low-quality seller has to incur in order to stay in the market are $C(q_{min}) - C(q_L^{ur})$. Since C' is continuous, $[C(q_{min}) - C(q_L^{ur})] \rightarrow 0$ as $q_{min} \rightarrow q_L^{ur}$. Thus, if q_{min} is set sufficiently close to q_L^{ur} , the revenues of the

⁷ Holding market shares constant, a social planner would maximize $q \int s ds - C(q)$ in each market segment. Hence, $\int s ds - MC > 0$ implies an under-provision of quality.

⁸ While there are conditions for which the two-firm equilibrium is unique – namely if $R_L(q_M, q_L^{ur}) - C(q_L) > 0$ or $R_H(b_H(q_M), q_M) - C(b_H(q_M)) > 0$, it is not clear what properties of the cost function, $C(\cdot)$, imply these conditions.

low-quality seller if he meets the standard (while the other firm produces q_M), $R_L(q_M, q_{min})$, exceed the costs of meeting the standard. In that sense, having one firm exit the market and the other produce the monopolistic quality cannot be an equilibrium.

When the minimum quality is set above q_* (as defined in Theorem 2), the market can no longer accommodate two sellers, and the monopolistic equilibrium is unique. In that case the policy outcomes identified in previous theorems are reversed. Market participation declines from $[x_L^{ur}, 1]$ to $[\frac{1}{2}, 1]$ and all remaining participants purchase a product of lower quality (q_M compared to q_H^{ur}). The policy implication of the last observation is straightforward. The success or failure of a minimum quality policy depends critically on the regulator's ability to fine tune the level of the quality standard.

4 Generalizations

In this section we show that the major results of Section 3 are extended to markets with infinitely many potential entrants and are not necessarily affected by the presence of quality-dependent variable costs.

Variable Costs. The model developed in Section 2 assumes that all quality-dependent costs are fixed costs that are borne upfront in the first stage of the game. This simplifying assumption enables a clear demonstration of the price-competition effect of minimum quality standards: an appropriately chosen minimum quality standard increases price competition and thus reduces (quality-deflated) prices. Quality-dependent costs, however, can also occur in the second-stage of the game when actual production takes place. These unit costs, unlike the fixed costs, enter directly into the competitors' pricing strategies, and therefore, if these costs increase in the quality produced, the MQS policy – by raising the qualities produced – can push prices up.

To see under what conditions this variable-cost effect will be dominated by the price-competition effect, let $v(q)$ be the cost of producing one unit of quality q in the second-stage of the game, and assume that $v' > 0$ and $v(0) = 0$. As in

Section 2, we assume that qualities are chosen in the first-stage of the game. A straightforward extension of the Appendix shows that the second-stage subgame has a unique price equilibrium. In this equilibrium, the quality-deflated prices, x_H^v and x_L^v , are (hereafter the superscript v denotes the presence of variable costs)

$$\begin{aligned} x_H^v &= x_H + \frac{2r}{4r-1} \frac{v(q_H)}{q_H} + \frac{1}{4r-1} \frac{v(q_L)}{q_L} \\ x_L^v &= x_L + \frac{2r}{4r-1} \frac{v(q_L)}{q_L} + \frac{r}{4r-1} \frac{v(q_H)}{q_H}. \end{aligned}$$

The first term of each expression is the respective quality-adjusted equilibrium price when there are no variable costs (see equation (1)). These terms represent the price-competition effect on quality-adjusted prices, that is, as r decreases and price competition intensifies, x_H and x_L decrease also. The second term of each expression represents the variable-costs effect, that is, these terms increase in $v(q)$. Assuming that the imposition of q_{min} increases qualities and reduces r , one can show that when unit production costs are linear or concave ($v'' \leq 0$), the price-competition effect dominates the variable-cost effect. Therefore, the quality-adjusted prices fall ($dx_i^v/dq_{min} < 0$ for $i = L, H$),⁹ and hence there is an increase in market participation and qualities consumed.¹⁰

The conditions under which the MQS policy increases qualities and reduces r are as in previous sections: (1) b_H is upward sloping, (2) b_L cuts b_H from below (as in Figure 2), and (3) $b'_H < r$. The first two conditions guarantee that $dq_L = dq_{min}$ and $dq_H = dq_{min} b'_H > 0$; and when they are satisfied, the third condition guarantees the existence of the price-competition effect, i.e., that $dr/dq_{min} < 0$. Notice, however, that if each firm's second-stage profit function is strictly concave in its own quality (a standard condition), and if the derivative of each firm's marginal profits with respect to its opponent's quality is positive (see intuition in Section 2), then condition (1) is satisfied and conditions (2) and (3) are implied by the conditions for uniqueness and stability: $q_i(\partial M R_i^v / \partial q_i) + q_j(\partial M R_i^v / \partial q_j) \leq 0$ for $i = L, H$ and $j \neq i$.¹¹ In other words,

⁹To verify, use the following observations: (1) $v'' \leq 0$ implies that $v(q)/q$ is constant or decreases in q , and (2) in equilibrium, it must be the case that $v(q_i)/q_i < 1$ for $i = L, H$, since positive consumer surplus, $sq_i - p_i > 0$, and $s \in [0, 1]$ imply $q_i > p_i$, and positive profits implies $p_i > v(q_i)$.

¹⁰Clearly, for continuity reasons, the price-competition effect dominates the variable-cost effect when v is slightly convex.

¹¹The interpretation of these conditions is that own effects of quality on marginal profits

the conditions guaranteeing uniqueness and stability also ensure the existence of the price competition effect. All of the conditions above are easily verified for the case of linear variable costs.¹²

Multiple Firms. Consider the same market as in Section 2 with the following two modifications: there are now infinitely many potential entrants, each of them faces the same cost structure, $C(q) + f$, where f is some “small” fixed entry cost. We added f to the cost structure so that an equilibrium in which only finitely many competitors enter the market can exist in the absence of a minimum quality standard.¹³

It is obvious that if two rivals enter the market with the same quality at the first stage, they will both earn zero revenues at the second stage due to the price competition. Thus, in an unregulated market equilibrium, if it exists,¹⁴ $k < \infty$ rivals enter the market with different qualities, $q_1^{ur} < q_2^{ur} < q_3^{ur} < \dots < q_k^{ur}$. The equilibrium quality-adjusted prices will be ordered in the same way, $x_1^{ur} < x_2^{ur} < x_3^{ur} < \dots < x_k^{ur}$, with respected market shares of $[x_1^{ur}, z_2^{ur}]$, $[z_2^{ur}, z_3^{ur}]$, $[z_3^{ur}, z_4^{ur}]$, $\dots$, $[z_k^{ur}, 1]$, where $z_i = (p_i - p_{i-1})/(q_i - q_{i-1})$.

A straightforward extension of Theorem 2 shows that there exists a quality q_* such that if q_{min} is set within (q_1^{ur}, q_*) , then (1) k rivals still enter the market; (2) the lowest-quality seller raises his quality to q_{min} , which makes him a closer substitute to the second-lowest seller; (3) to relax price competition, the second-lowest seller raises his quality, which makes him a closer substitute to third-lowest seller; and so on $\dots$. The new equilibrium will have $q_i^{mq} > q_i^{ur}$ for all k entrants. However, since the minimum quality standard reduces the set of qualities from which firms can choose, from $[0, \infty)$ to $[q_{min}, \infty)$, and since quality

dominate cross effects. When there are no variable costs or when they are linear (see below), these conditions are satisfied with equality due to Euler’s theorem (see footnote 4).

¹²One can show that if $v(q) = aq$ and $a < 1$, then $R_H^v = (1 - a)^2 R_H$ and $R_L^v = (1 - a)^2 R_L$. Thus, all the properties of R_H and R_L used in previous sections are also the properties of R_H^v and R_L^v .

¹³It is easily verified that when $f = 0$ and there is no minimum quality standard, a firm can always enter the market with very low quality and obtain positive profits. Thus, under these assumptions, the only possible equilibrium has infinitely many rivals in the market.

¹⁴The main point of the paper is to compare an equilibrium with an appropriate minimum quality standard with the unregulated equilibrium. If the pure strategy equilibrium fails to exist in the absence of regulation, there is no reason for making this comparison.

improvements involve increasing marginal costs, the k rivals find themselves closer to each other despite their efforts to alleviate price competition. This in turn implies a more intense price competition that results in lower hedonic prices, i.e., $x_i^{mq} < x_i^{ur}$ for all k rivals. Parts (b) and (c) of Theorem 2 and Theorems 3 and 5 generalize straightforwardly.

5 Summary

This paper has demonstrated that concerns raised in previous papers about adverse consequences of minimum quality standards might not be valid. I have shown that if the standard is chosen appropriately, (1) none of the consumers will drop out of the market, and some other consumers who are not active in the unregulated market will join the market; and (2) all participating consumers will raise their quality selection, even those whose selections exceed the standard in the absence of regulation. These two issues are pivotal when the consumption of higher-quality goods generates positive externalities or reduces negative externalities (e.g., safety goods and fuel-efficient cars). Moreover, the paper has demonstrated that even in the absence of externalities, qualities are “underprovided” and “excessively” differentiated (the latter causes a thin market participation) so that a minimum quality standard, by increasing qualities and reducing differentiation, improves social welfare. Whether or not externalities exist, a major obstacle to the imposition of a socially improving standard are consumers who fear they will face higher prices and less variety. Contrary to previous research this paper has shown that no consumer stand to lose from an appropriately chosen standard.

These results are explained by the competitors’ incentives to differentiate qualities in order to relax price competition. To alleviate the effects of the more intense price competition on their revenues, high-quality sellers raise their quality in reply to the low-quality sellers having raised their quality to the mandated minimum quality level. However, by its very nature, a minimum quality standard limits the range in which producers can differentiate qualities. Hence, in the end, price competition intensifies despite the high-quality sellers’

efforts to relax it. Consequently, if variable costs do not rise “too quickly” with quality, prices – “corrected for quality change” – fall. The combination of better qualities and lower hedonic prices accounts for the results listed above.

The positive effects of a quality standard identified in this paper, however, are dependent on the regulators’ ability to fine tune the standard. In particular, if the standard is set too high, fewer firms will enter the market, and as a result, the policy outcomes will be diametrically opposed to those listed above.

Appendix

The Second-Stage Price Equilibrium

Recall the following notation: $x_H \equiv \frac{p_H}{q_H}$, $x_L \equiv \frac{p_L}{q_L}$, $z \equiv \frac{p_H - p_L}{q_H - q_L}$, and $r \equiv \frac{q_H}{q_L}$. The price equilibrium when $q_H = q_L$ is easily shown to be $p_H = p_L = 0$. So assume $q_H > q_L$. We start by calculating the reaction function of the high-quality seller. Note that consumer s buys the high-quality product if and only if (1) $s \geq x_H$ (she gets a positive surplus)¹⁵ and (2) $s \geq z$ (her surplus from the high-quality product is higher than her surplus from the low-quality product).¹⁶ Since $\max\{x_H, z\}$ equals x_H if $x_H \leq x_L$ and equals z if $x_H \geq x_L$, and since s is distributed uniformly on $[0, 1]$, we conclude that the high-quality seller’s market share is $[x_H, 1]$ if $x_H \leq \min\{x_L, 1\}$; $[z, 1]$ if $1 \geq x_H \geq x_L$ and $z \leq 1$; and $\emptyset$ otherwise. This implies that if $x_L \geq 1/2$, his optimal response is the (quality-deflated) monopolistic price $x_H = 1/2$. The best response against $x_L \leq 1/2$ is obtained by solving $\max_{x_H} (1 - z)x_H$ subject to $x_H \geq x_L$, for all $x_L \in [0, \frac{1}{2}]$. This yields the high-quality seller’s reaction function below (second-order conditions are easily verified):

$$x_H(x_L) = \begin{cases} \frac{1}{2} & \text{for } x_L \geq \frac{1}{2} \\ x_L & \text{for } \frac{1}{2} \geq x_L \geq \frac{r-1}{2r-1} \\ \frac{1}{2r}[x_L + (r-1)] & \text{for } \frac{r-1}{2r-1} \geq x_L \geq 0. \end{cases}$$

Next we find the low-quality seller’s reaction function. His market share is $\emptyset$ if $x_L \geq x_H$; $[x_L, z]$ if $x_L \leq x_H$ and $z \leq 1$; and $[x_L, 1]$ if $x_L \leq x_H$ and $z \geq 1$.¹⁷ This

¹⁵This is equivalent to $sq_H - p_H \geq 0$.

¹⁶This is equivalent to $sq_H - p_H \geq sq_L - p_L$.

¹⁷This represents the solution to the following system of equations: (a) $sq_L - p_L \geq 0$; (b) $sq_L - p_L \geq sq_H - p_H$; and (c) $s \leq 1$.

implies that if $x_H \geq (2r - 1)/2r$, his optimal response is $x_L = 1/2$. The rest of the reaction function is obtained by solving $\max_{x_L} (z - x_L)x_L$ subject to $z \leq 1$, for all $x_H \in [0, \frac{2r-1}{2r}]$. This yields the low-quality seller's reaction function below (second-order conditions are again easily verified):

$$x_L(x_H) = \begin{cases} \frac{1}{2} & \text{for } x_H \geq \frac{2r-1}{2r} \\ rx_H - (r-1) & \text{for } \frac{2r-1}{2r} \geq x_H \geq \frac{2r-2}{2r-1} \\ \frac{1}{2}x_H & \text{for } \frac{2r-2}{2r-1} \geq x_H \geq 0. \end{cases}$$

The two reaction curves intersect uniquely at the (quality-deflated) equilibrium prices $x_H = \frac{2(r-1)}{4r-1}$ and $x_L = \frac{r-1}{4r-1}$. The equilibrium market share of the high-quality seller and the low-quality seller are therefore $1 - z = \frac{2r}{4r-1}$ and $z - x_L = \frac{r}{4r-1}$, respectively.

Proof of Theorem 1, Parts (b) and (c)

(b) From Figure 1 it is clear that one can always earn positive profits if he enters as the low-quality seller, i.e., $\int_0^{b_L(q_H)} [MR_L(q_H, t) - MC(t)] dt > 0$ for all $q_H > 0$. We now show that in equilibrium the high-quality seller earns more than the low-quality seller, and hence, his profits are also positive:

$$\begin{aligned} R_H(q_H^{ur}, q_L^{ur}) - R_L(q_H^{ur}, q_L^{ur}) &\stackrel{(a)}{=} (q_H^{ur} - q_L^{ur}) \frac{r^{ur}}{4r^{ur}-1} \stackrel{(b)}{>} \\ (q_H^{ur} - q_L^{ur}) MR_H(q_H^{ur}, q_L^{ur}) &\stackrel{(c)}{=} (q_H^{ur} - q_L^{ur}) C'(q_H^{ur}) \stackrel{(d)}{>} C(q_H^{ur}) - C(q_L^{ur}); \end{aligned}$$

where (a) follows from equation (2); (b) follows from writing MR_H and MR_L explicitly: MR_H is bounded by $\frac{4}{9}$ from above (since $MR_H(q, q) = \frac{4}{9}$ for all q), and r^{ur} is bounded by $\frac{7}{4}$ from below (since $MR_L(q_H^{ur}, q_L^{ur}) > 0$); (c) follows from (??-b); and (d) follows from the assumption that $C'' > 0$.

(c) Let $\Pi_L(q_H) \equiv R_L(q_H, b_L(q_H)) - C(b_L(q_H))$, and let $\Pi_H(q_L) \equiv R_H(b_H(q_L), q_L) - C(b_H(q_L))$. We first prove the following claim: $\Pi_L(q_H)$ increases in q_H , and $\Pi_H(q_L)$ decreases in q_L . To prove the first part of the claim, let $\bar{q}_H > \bar{q}_H$. Since b_L is a best-response function and R_L increases in q_H , we conclude that $\Pi_L(\bar{q}_H) \geq R_L(\bar{q}_H, b_L(\bar{q}_H)) - C(b_L(\bar{q}_H)) > \Pi_L(\bar{q}_H)$, and therefore, $\Pi_L(q_H)$ increases in q_H . To prove the second part of the claim, let $\bar{q}_L > \bar{q}_L$. Since $b_H(\cdot)$ is a

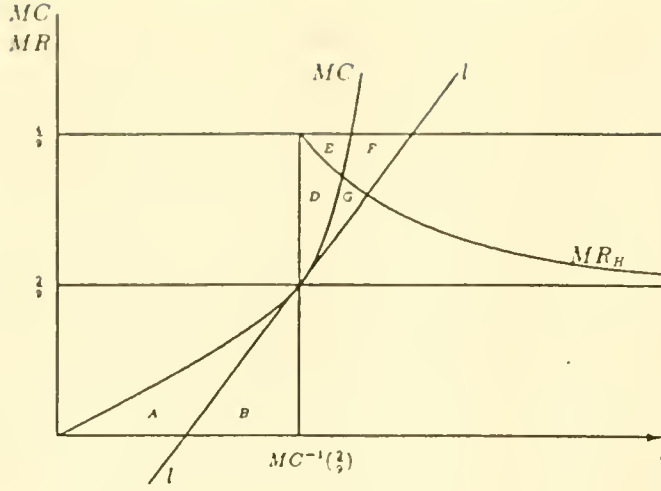


Figure 4: Proof of part (c), Theorem 1

best response function and R_H decreases in q_L , we conclude that $\Pi_H(\bar{q}_L) \geq R_H(b_H(\bar{q}_L), \bar{q}_L) - C(b_H(\bar{q}_L)) > \Pi_H(\bar{q}_L)$, and therefore, $\Pi_H(q_L)$ decreases in q_L . We use the first part of the claim to show that q_H^{ur} is always a global best response against q_L^{ur} , that is, $\Pi_H(q_L^{ur}) > \Pi_L(q_L^{ur})$, *irrespective* of the sign of C''' :

$$\Pi_H(q_L^{ur}) = R_H(q_H^{ur}, q_L^{ur}) - C(q_H^{ur}) > R_L(q_H^{ur}, q_L^{ur}) - C(q_L^{ur}) = \Pi_L(q_H^{ur}) > \Pi_L(q_L^{ur}),$$

where the first inequality is proved in part (b). We use the second part of the claim to show that if $C''' > 0$, then q_L^{ur} is a global best response to q_H^{ur} . In Figure 5, each capital letter stands for its respective area, and the line ll is the tangent of MC at $(MC^{-1}(\frac{2}{9}), \frac{2}{9})$. (The line ll is below the MC curve because $C''' \geq 0$. Also, recall that $MR_H(q, q) = \frac{4}{9}$ for all $q > 0$, and in particular for $MC^{-1}(\frac{2}{9})$.) In the figure, $\Pi_H(MC^{-1}(\frac{2}{9})) = D - (A + B)$. By construction, $B = D + E + F + G$. Therefore, $A + B > D$, which implies that $\Pi_H(MC^{-1}(\frac{2}{9})) < 0$. Since, by equation (3-a), $q_H^{ur} > q_M > MC^{-1}(\frac{2}{9})$, the second part of the above claim implies that $\Pi_H(q_H^{ur})$ is also negative. Therefore, $\Pi_L(q_H^{ur}) > \Pi_H(q_H^{ur})$, i.e., q_L^{ur} is a global best response to q_H^{ur} . ■

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